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JUL 81 J D WORTMAN, C W KITCHENS, R E LOTTERO
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MEMORANDUM REPORT ARBRL-MR-03114

(Supersedes IMR No. 685)

PREDICTION OF 3-D BLAST LOADING ON A PARTIALLY-OPEN INDUSTRIAL BUILDING: FEASIBILITY STUDY

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July 1981

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
BALLISTIC RESEARCH LABORATORY
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) (bas) The modified 3-D HULL hydrocode is used to calculate the blast loading on a partially-open, industrial-type building struck by a 32.8 kPa (4.75 psi) overpressure shock at oblique incidence. The feasibility of predicting the net unsteady loading on the front and back walls of the building is demonstrated. The predicted loading appears to be qualitatively correct; further studies will be necessary to assess the quantitative results and extend the analysis to other types of structures.

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I. INTRODUCTION

Blast effects from nuclear weapons are directly responsible for various forms of structural damage to residential and industrial buildings. A considerable amount of information about the blast response of full-scale and model structures has been obtained in previous nuclear and high-explosive test programs.[1] However, in many cases correlation between the observed structural damage and the predicted results has been hampered by uncertainties in the blast loading history on the structures. These uncertainties in the blast loading have typically been experienced for industrial-type structures, typified by the partially-open industrial building[1] shown in Figure 1. This building has a steel framework covered with concrete siding and a frangible metal roof. The concrete siding only partially covers the two walls, leaving a considerable part of the wall area open. The level of blast damage experienced by a given structure is a function of the blast wave peak overpressure, the positive phase duration (yield), and the orientation of the structure with respect to the incident shock. The prediction of the unsteady blast loading on such structures is difficult because of the complex geometry.

Success was recently achieved at the BRL in predicting the blast loading on an S-280 Electrical Equipment Shelter struck at an oblique angle by a 32.8 kPa (4.75 psi) overpressure step shock.[2] The shelter is essentially a rectangular parallelepiped, 3.62 m wide, 2.17 m deep, and 2.11 m high. The numerical results were obtained using a modified version* of the three-dimensional (3-D) HULL hydrocode,[3] which solves the inviscid Euler equations. The shelter was modeled in the computational flow field as a rigid obstacle sitting on a perfectly reflecting ground plane. It was oriented so that its front face (one of the two 3.62 m by 2.11 m faces) was at a 52.5 degree angle to the oncoming shock

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[1] *S. Glasstone, and P. J. Dolan (Ed.), "The Effects of Nuclear Weapons," Dept. of Army Pamphlet 50-3, March 1977.*

[2] *R. E. Lottero, J. D. Wortman, B. P. Bertrand and C. W. Kitchens, Jr., "Oblique Interaction of a Shock Wave with a Tactical Communications Shelter," Proceedings of the 1980 Army Numerical Analysis and Computers Conference, Moffett Field, CA, 21-22 February 1980.*

* *The modifications were made to the AFWL version[3] at the BRL both by the BRL and by individuals under contract to the BRL. The modified version has been given to AFWL.*

[3] *M. A. Fry, R. E. Durrett, G. P. Ganong, D. A. Matuska, M. D. Stucker, B. S. Chambers, C. E. Needham, and C. D. Westmoreland, "The HULL Hydrodynamics Computer Code," AFWL-TR-76-183, U.S. Air Force Weapons Laboratory, Kirtland Air Force Base, NM (September 1976).*

wave front, with the angle measured between the front face and the wave front. The accuracy of these 3-D calculations was verified by comparison with experimental results taken in the BRL 0.6 m (24 inch) diameter[4] shock tube using a 1/18 scale-model shelter.

Figure 2 shows a comparison between the predicted and measured overpressure histories at a typical point on the shelter front face. Every fifth computed data point on the curve of the predicted results from HULL has been marked with an "X" for ease in differentiating between the two curves. The experimental results show a shock which has reflected from the shelter, traveled to the shock tube wall, and reflected from it, arriving at the gage on the front face at 1.2 ms. This "interference effect" was not simulated in the computation because the computational boundaries, except for the ground plane, are transmissive. The results are in good agreement; similar good agreement was found in the comparisons for other shelter faces (not shown here). The conclusion from this work was that the modified 3-D HULL hydrocode can provide accurate blast loading predictions (errors less than approximately 10%) for this class of problems at moderate cost.

The main difference between a computational study of an open industrial structure[1] and that for the shelter model[2] is that a hollow, thin-walled structure with both internal and external flow must be modeled instead of a solid structure with only external flow. However, these two problems are of the same class, and hence HULL should be expected to provide an accurate computation for the open structure. This is an area in which hydrocodes have not yet been properly exploited but could be used to provide the loading as a function of time on the walls, roofs, and floors of such structures. More sense could then be made of existing experimental data, and information could be generated where none now exists. This report describes the computations in this feasibility study and presents typical results to illustrate that blast loading at arbitrary obliquity on open industrial structures can be predicted by computational means.

II. DESCRIPTION OF COMPUTATION

The approach adopted in this study has been to exploit the demonstrated capability[2] of the BRL's version of HULL to predict loading on 3-D structures from oblique shock diffraction. This was done by adapting the 3-D computational grid for the shelter model to simulate an identical shock wave at the same angle of obliquity diffracting over an open industrial building. The building was "constructed" by hollowing out the shelter model, leaving front and

[4] *G. A. Coulter and B. P. Bertrand, "BRL Shock Tube Facility for the Simulation of Air Blast Effects," U.S. Army Ballistic Research Laboratory Memorandum Report No. 1685, August 1965, (AD 475669).*

back walls that were one cell thick. The shelter endwalls were removed and the flat roof was replaced with a peaked roof. Window openings were added at the centers of both remaining walls, leaving 12.5% of the wall area open. The windows are one-fourth of the wall height and one-half of the wall length in size.

Figure 3 shows a schematic view of the model structure treated in this study. The peaked roof is irregular because rectangular parallelepiped cells (which are either all hydrodynamic or all rigid) are used in the present version of 3-D HULL; future work is planned to eliminate this shortcoming. The roof slope increases slightly with height due to the use of a variable mesh; this can easily be refined in further studies.

The complete finite-difference grid consists of 92,512 cells, with 49 × 59 × 32 cells in the X,Y, and Z directions, respectively. The model structure is placed on the ground plane (Z = 0), roughly in the center of the X-Y plane. Figure 4 is a top view of the computational grid, showing the grid boundaries, the location of the structure within the grid, and the position of the incident shock at the start of the calculation (t = - 0.07 ms). By definition, the shock strikes the leading edge of the structure at t = 0. The mesh size inside and immediately adjacent to the structure is approximately 0.74 × 0.73 × 0.71 cm. The mesh size geometrically increases with distance away from the building, giving approximately a 7% variation in size between adjacent cells. The transmissive grid boundaries are located far enough away from the structure that more than 1 ms of the loading process can be simulated for this model size. (Wave interactions with transmissive grid boundaries can send artificial waves back into the computational flow field.) A computational grid simulating a larger region around the model would have to be used in order to compute farther out in time to have confidence that artificial waves were not reaching regions of interest. The 32.8 kPa shock impinges on the front wall of the structure at an angle of 52.5°. This angle was chosen because it produces a peak reflected pressure on the front face that is larger than that for normal reflection (for a nominal 34.5 kPa shock).

Figure 4 also shows the location of four positions (A through D) on the front and back walls of the structure at which predicted pressure-time histories will be presented. These points are located at Y = 34.7 cm and Z = 2.8 cm, slightly below the window openings. The computational results for this problem were obtained in approximately 30 minutes of CPU time on the BRL Cyber 76 computer.

III. DISCUSSION OF RESULTS

Figures 5-8 present a qualitative indication of the three-dimensional diffraction process occurring as the shock transits the model structure. Figures 5a - 8a show a time sequence of isobars (pressure

contours) in a horizontal plane (Z = 5.3 cm) which passes through the window openings, just below the middle of the windows. The shock is moving from the lower left corner of the figure, approximately toward the upper right. It is depicted by the concentration of isobars. Figures 5b - 8b show the same time sequence of isobars in an orthogonal view; this vertical plane passes through approximately the middle of the building (Y = 29.8 cm). The sequence of figures also gives an indication of the shock movement through the grid. The contour numbers indicated on the figures refer to overpressure levels. The waviness of the contour lines near the grid boundaries is an artifact of the contour-drawing algorithm, which is further accentuated by the high aspect ratios of the flow field cells in those regions.

The reflection of the incident shock from the front and back walls can be traced through Figures 5a - 7a. The back wall is partially shielded from the incident shock wave by the presence of the front wall; this effect can be seen in Figures 7a and 8a. Figures 5b - 7b show the progression of the diffracted shock through the windows and over and along the peaked roof. Figures 8a and 8b illustrate the late-time diffraction process as the incident shock reaches the rear-most corner of the structure relative to the corner which the shock first encounters.

Quantitative comparisons of the computed results have been made between the loading at opposite positions on both the front and back walls to demonstrate the significance of shielding effects. Figure 9 shows the predicted overpressure histories at positions A (outside surface) and B (inside surface) on the front wall. The curve for position A has every fifth computed point marked with an "X" for ease of differentiation between the two curves. (The curve for point D on Figure 10 is similarly marked.) The computed loading histories are consistent with the qualitative results in Figures 5 - 7. The net loading at this position is directed inward until approximately t = 0.7 ms, at which time the direction momentarily reverses, apparently due to the arrival of waves reflected from the back wall.

Figure 10 shows a similar comparison between the overpressure histories at positions C (inside surface) and D (outside surface) on the back wall. The net loading at this position is directed outward during the time interval shown, with a loading history that is quite different from that shown in Figure 9. In this case a secondary peak at t = 0.9 ms in the net loading at this position is apparently caused by waves reflected from the inside of the front wall.

IV. CONCLUSIONS

This feasibility study has shown that the modified 3-D HULL hydrocode can be used to predict the blast loading on a fairly complex industrial-type building. The qualitative results exhibit the features expected during such a shock diffraction process. The net loading

history on the walls of the structure can easily be obtained from the computed results for use in structural response analysis.

It should be recognized, however, that the accuracy of the predicted blast loading history has not been established for this case. Further numerical studies, including comparisons with experimental data, will be needed to validate the predicted loading on such buildings and assess the overall accuracy of the results. At this point we are optimistic that the results will prove to be accurate enough to be useful in analyzing the response and vulnerability of such structures.

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2. R. E. Lottero, J. D. Wortman, B. P. Bertrand and C. W. Kitchens, Jr., "Oblique Interaction of a Shock Wave with a Tactical Communications Shelter," Proceedings of the 1980 Army Numerical Analysis and Computers Conference, Moffett Field, CA, 21-22 February 1980.

3. M. A. Fry, R. E. Durrett, G. P. Ganong, D. A. Matuska, M. D. Stucker, B. S. Chambers, C. E. Needham, and C. D. Westmoreland, "The HULL Hydrodynamics Computer Code," AFWL-TR-76-183, U.S. Air Force Weapons Laboratory, Kirtland Air Force Base, NM (September 1976).

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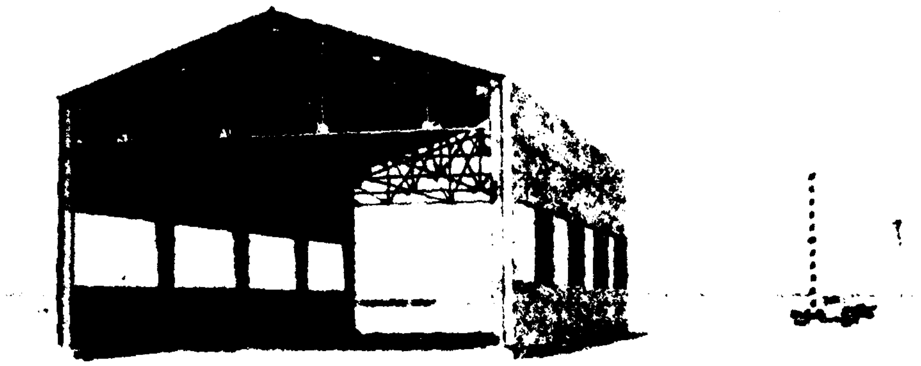


Figure 1. Steel-frame industrial building (from Glasstone and Dolan[1]).

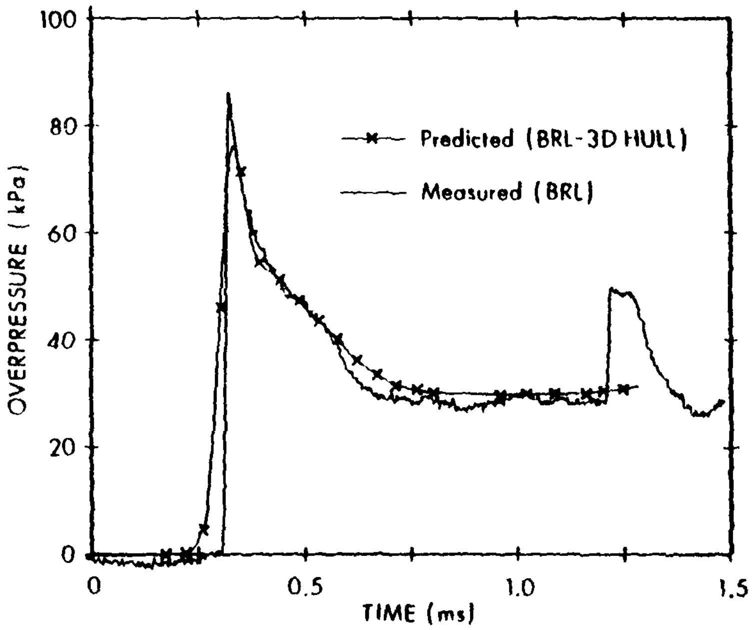


Figure 2. Comparison of predicted and measured overpressure-time histories at typical point on front face of S-280 Electrical Equipment Shelter model (from Lottero et al.[2]).

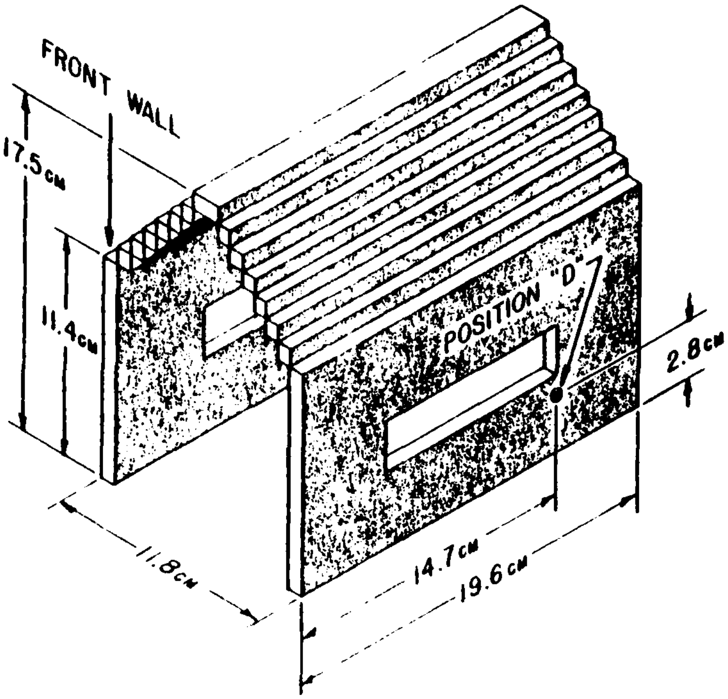


Figure 3. Schematic of partially-open industrial building modeled in 3-D grid.

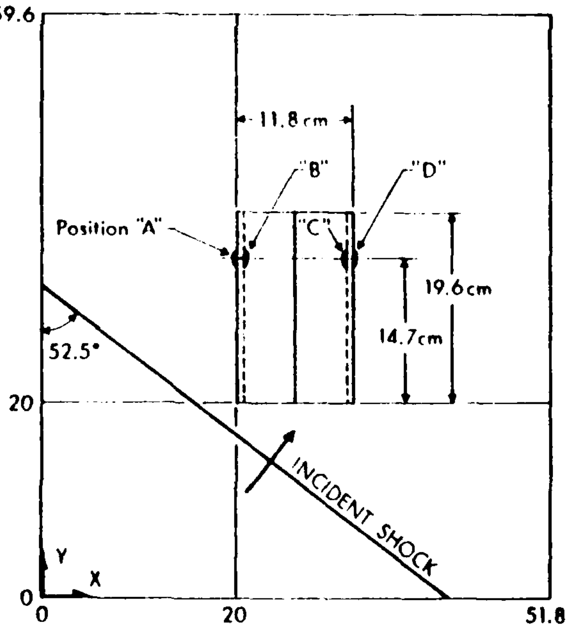


Figure 4. Top view of computational grid showing initial shock position (ground plane).

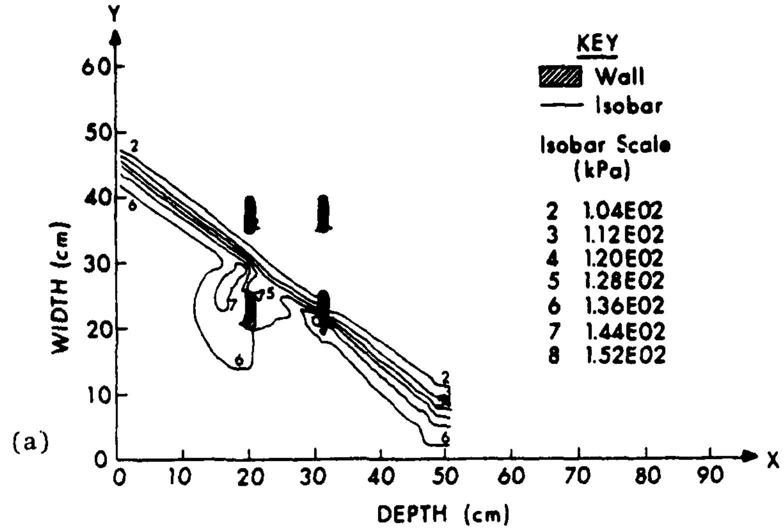
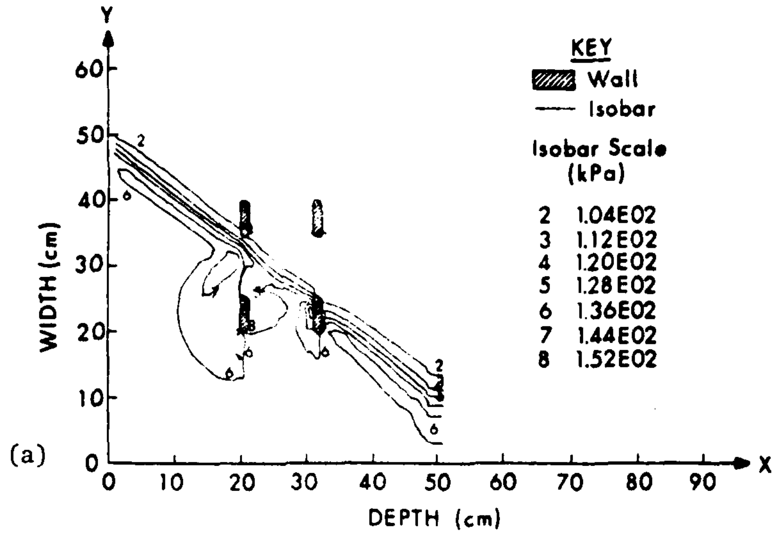


Figure 5. Isobars predicted at t = 0.23 ms; (a) Z = 5.3 cm, (b) Y = 29.8 cm.



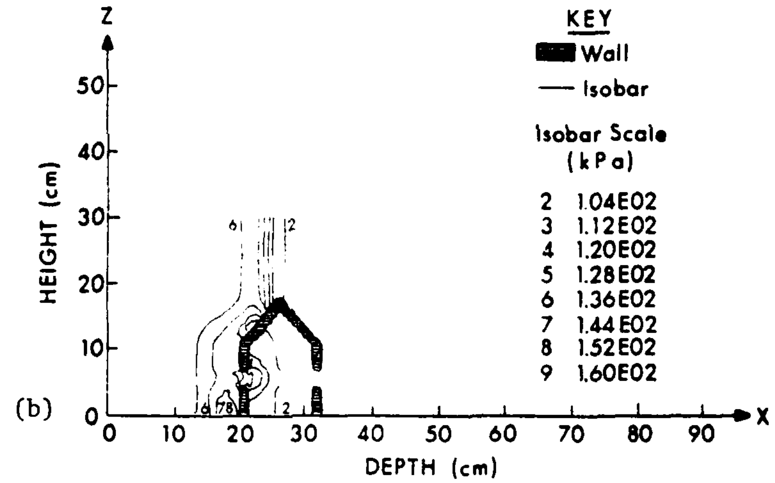
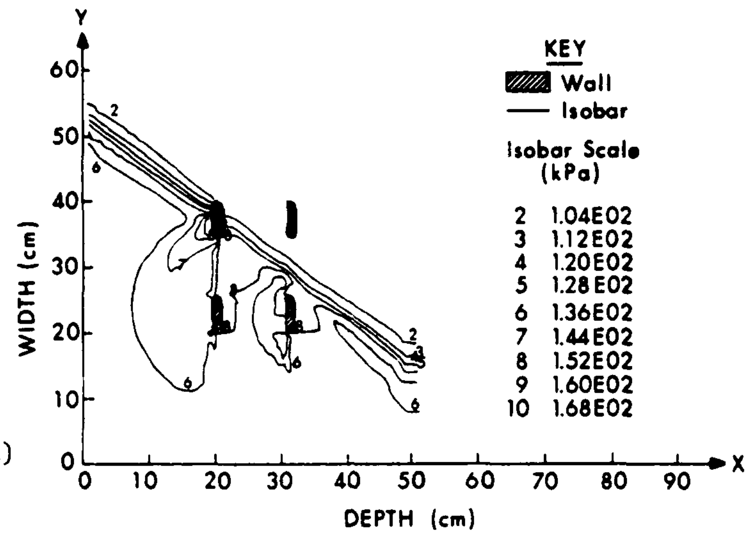
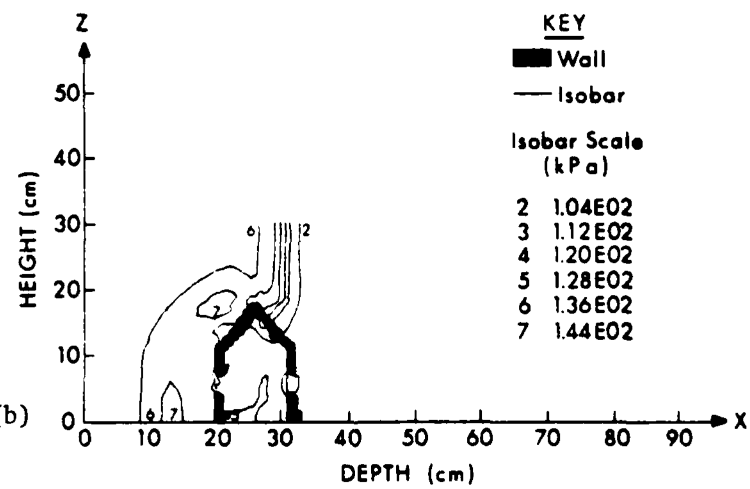


Figure 6. Isobars predicted at t = 0.28 ms; (a) Z = 5.3 cm, (b) Y = 29.8 cm.



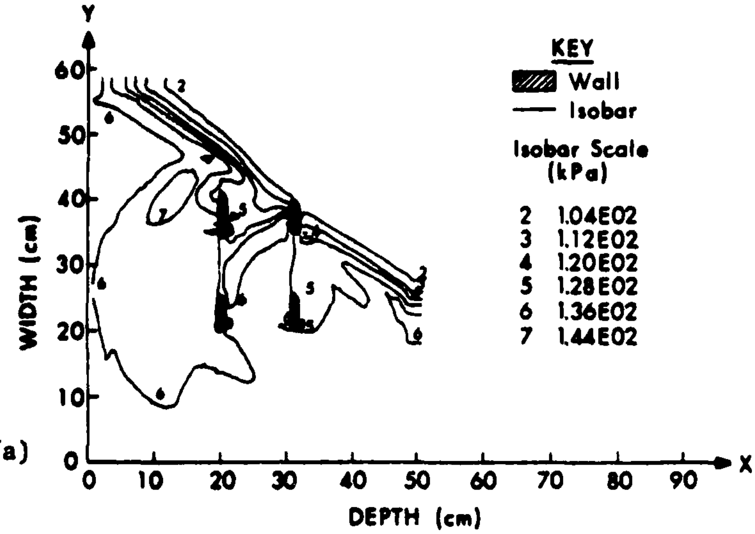
(a)



(b)

Figure 7. Isobars predicted at t = 0.38 ms; (a) Z = 5.3 cm, (b) Y = 29.8 cm.

(a)



(b)

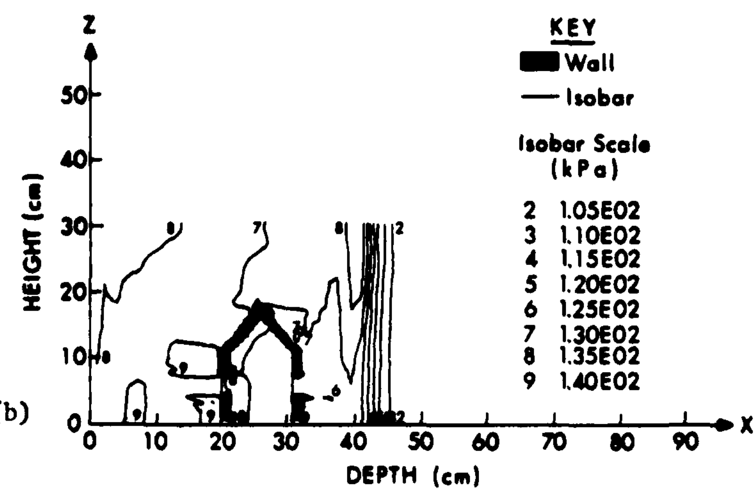


Figure 8. Isobars predicted at t = 0.58 ms; (a) Z = 5.3 cm, (b) Y = 29.8 cm.

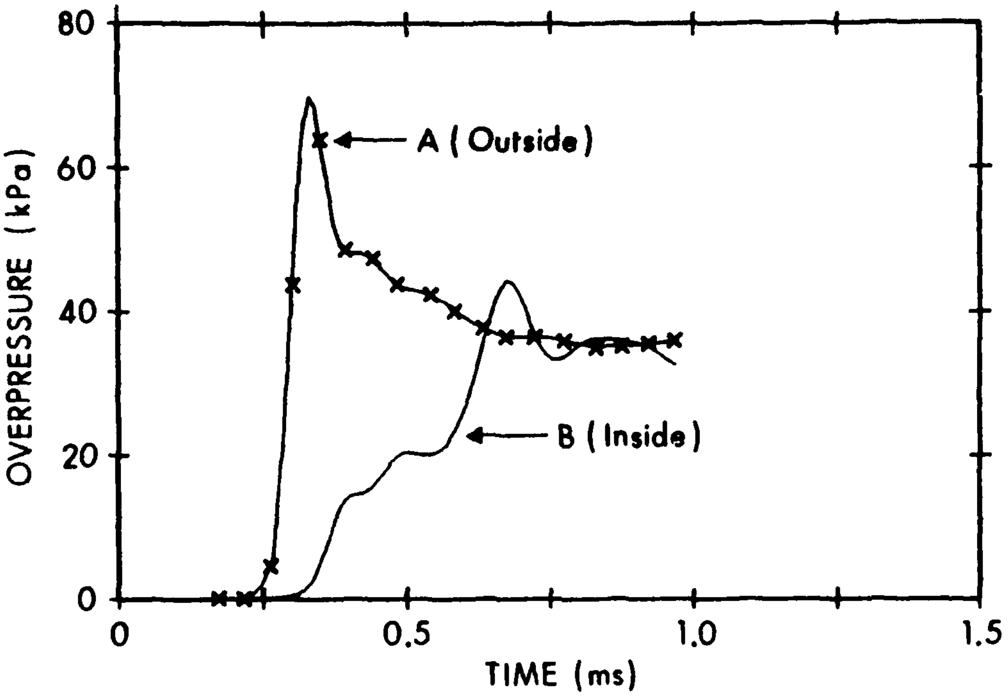


Figure 9. Predicted overpressure histories at positions A and B on front wall of building.

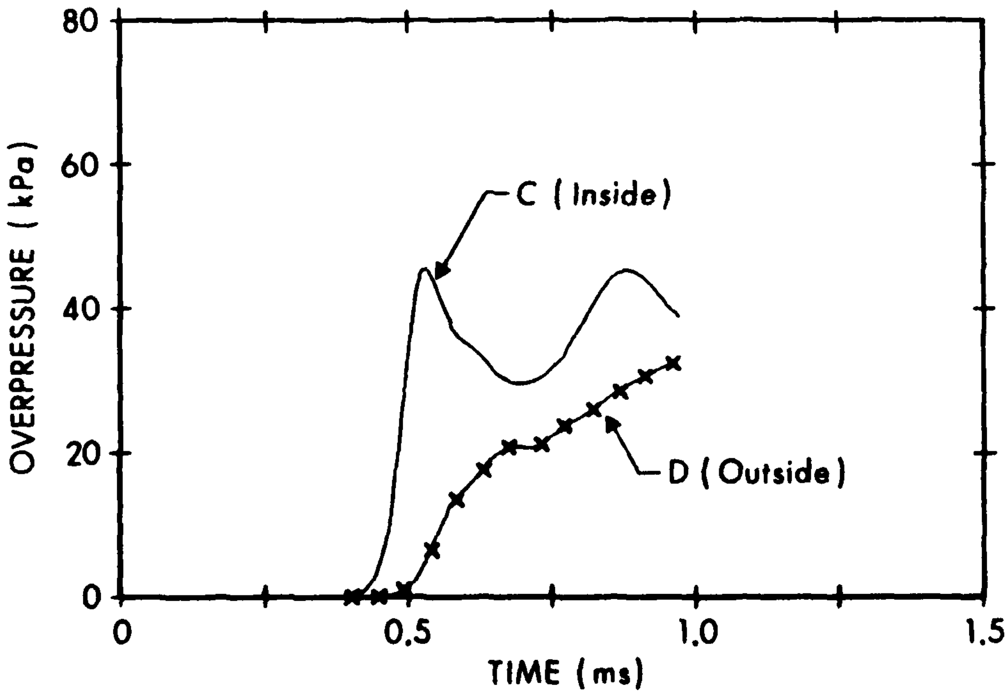


Figure 10. Predicted overpressure histories at positions C and D on back wall of building.

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